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REPORT

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A LIGHTWEIGHT IMPERMEABLE SUIT FOR CHEMICAL PROTECTION IN WARM CONDITIONS: A PRELIMINARY LOOK AT THE CONCEPT

R. Ian Tilley, Jill M. Standerwick, Geoffrey J. Long & Hugh D. Crone

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POSTAL ADDRESS: Director, Materials Research Laboratories
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

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A lightweight impermeable suit for chemical protection in warm conditions: a preliminary look at the concept

AUTHOR(S)	CORPORATE AUTHOR
R. Ian Tilley Jill M. Standerwick Geoffrey J. Long and Hugh D. Crone	Materials Research Laboratories P.O. Box 50, Ascot Vale, Victoria 3032

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A lightweight overgarment made of spun-bonded polyethylene was compared with the UK No. 1 Mk 3 NBC suit in terms of the heat burden imposed on wearers. The physiological responses of volunteers exercising in warm conditions were measured for both clothing ensembles and were found to be similar. These results suggested that the concept of a lightweight impermeable NBC suit for wear in jungle conditions was worthy of close investigation. Results also confirmed previous observations that soldiers wearing NBC clothing in warm and humid conditions could do little more than adopt a defensive position if they were not to become heat stress casualties.

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A LIGHTWEIGHT IMPERMEABLE SUIT FOR CHEMICAL PROTECTION IN WARM CONDITIONS: A PRELIMINARY LOOK AT THE CONCEPT

1. INTRODUCTION

NBC protective clothing is hot, uncomfortable and burdensome to wear. Some nations, amongst them Canada, the United States, the United Kingdom, France and Italy, field NBC suits made from air-permeable fabrics while others, the USSR, Israel and Norway for example, use impermeable materials. Permeable fabrics have been used in the manufacture of NBC suits in an effort to ease the heat burden imposed on wearers; protection depends on liquid repellency and vapour absorption by charcoal. However, the anticipated benefits deriving from the use of permeable fabrics are limited by three factors.

Firstly, effective circulation of air between the suit and a soldier's body is prevented by personal equipment such as belt, webbing and packs. If an impermeable hood such as the US M6A2 is worn air circulation around the head is prevented and any cooling available through the chimney effect is precluded. The only parts of the body where some circulation of air is possible are the arms and legs.

Secondly, sweat produced on the skin must be transmitted to the outer layer of clothing before it can be effectively evaporated, and thirdly the cooling effect of such evaporation has to pass a number of layers of air and fabric before it is felt at the skin surface when it is needed for cooling a hot individual. The ambient air may well be cooled more than the body.

These limiting factors which apply to permeable NBC clothing worn in the field prompted a re-evaluation of the advantages which were thought to ensue from the use of such clothing. In particular, its use in a jungle, or close country, environment where ambient air movement is minimal was considered.

The concept of using a cheap lightweight coverall for liquid protection was considered to be worth examining. A commercially-available protective coverall made from Tyvek (Du Pont spun-bonded polyethylene) was assessed for its heat stress characteristics and compared with the UK No. 1 Mk 3 NBC suit under controlled laboratory conditions. Although the Tyvek garment provides limited protection against organic chemicals [1] it was considered to represent the concept of interest. If it proved to have equivalent or superior heat stress characteristics when compared to current permeable suits work could proceed to produce a similar suit having the desired chemical protection.

2. EXPERIMENTAL

Four clothing ensembles were studied, the first being Australian Army issue combat clothing consisting of long-sleeve shirt and trousers worn over cotton underwear. Shirt sleeves were buttoned at the wrist. The second ensemble consisted of a UK No. 1 Mk 3 NBC suit (smock and trousers) worn over the combat clothing together with the US M17A1 protective mask and M6A2 impermeable hood, US butyl rubber gloves and UK overboots. The third ensemble was the same as the second except that (i) the NBC suit was replaced by a one-piece Tyvek coverall (front-opening, zip-closure) and (ii) the M6A2 hood was not worn because the Tyvek garment incorporated an integral hood. The fourth ensemble was the same as the third except that the coverall was made from impermeable PVC. This ensemble was included as a representative of earlier heavyweight impermeable suits and limited experiments were performed for comparative purposes. A belt and two water canteens, webbing and ammunition pouches and a back pack were carried. The canteens were filled with water and weights were carried in the ammunition pouches and back pack.

Experiments were run in controlled environments of (i) 30°C and 40% relative humidity, and (ii) 30°C and 80% relative humidity. The only air movement in the environmental room was that produced by the air-conditioning equipment which was minimal.

Twelve fit, active and heat-acclimatised volunteers took part in the experiments. Their characteristics are given in Table 1. All were medically screened prior to the experiments to determine their fitness for work in hot conditions. The nature and purpose of the experiments were fully explained to each subject and their informed consent obtained in accordance with the Helsinki Code [2]. Experiments were performed with volunteers as they became available; consequently, not all clothing ensembles were worn by each volunteer.

After an initial rest period of 20 minutes in the test environment the volunteers attempted to walk at 5.6 km/hour on a level treadmill for 60 minutes in each environment. At the end of the exercise the belt, webbing and pack were removed and the participant sat while his recovery was monitored. Total loads of 20 to 25 kg, depending on the ensemble worn, were carried. Rectal temperatures and heart rates were recorded at intervals of 5

minutes during the rest and exercise periods and weight loss and sweat evaporated determined by weighing each subject nude and fully dressed before and after each experiment. A volunteer was withdrawn if (i) his rectal temperature reached 39.2°C, (ii) his heart rate was 180 beats/minute or (iii) signs of distress were noticed. Volunteers could also withdraw voluntarily at any time and for any reason.

3. RESULTS

3.1 Rest Period Prior to Treadmill Exercise

Changes in rectal temperature and heart rate occurring in the volunteers in the 20 minute period of rest prior to the treadmill exercise were insignificant. Mean rectal temperatures rose by 0.04 to 0.13°C while the corresponding heart rates varied by -7 to +2 beats per minute. Neither the clothing ensemble nor the environmental conditions had any significant effect on the two physiological variables.

3.2 Treadmill Exercise

Tables 2 to 8 summarise the results obtained. For all clothing ensembles endurance times were reduced at the higher relative humidity of 80%. The wearing of protective clothing also reduced endurance times with the PVC clothing having the greatest effect. There was no significant difference in endurance times obtained when volunteers wore either the NBC or Tyvek clothing.

The protective clothing ensembles and the higher humidity produced higher sweat rates and lower sweat evaporation with the PVC suit appearing to be the most burdensome. Wearers of the NBC and Tyvek suits experienced similar weight loss and sweat evaporation.

For comparative purposes the changes in rectal temperature (ΔT_R) and heart rate (ΔHR) occurring between 5 and 30 minutes after commencement of the exercise were determined for each clothing ensemble and environmental condition. They are given in Table 9. It can be seen that for each ensemble ΔT_R was greater at the higher humidity. Each of the protective clothing ensembles caused a higher ΔT_R than the combat clothing under each environmental condition (Student 't' test, probability (p) that the means are statistically different > 0.99). There is no statistical difference ($p < 0.9$) in ΔT_R values found for the protective clothing ensembles in either environment although the trend is to a higher ΔT_R for the PVC suit.

Heart rate changes showed a similar pattern to ΔT_R values with ΔHR for the protective clothing being significantly greater than that for combat clothing ($p > 0.99$). Heart rate increases associated with the

protective clothing ensembles were also similar with a trend to higher ΔHR values at the higher humidity.

3.3 Post-Exercise Recovery

Figure 1 shows the rise in rectal temperature for the last 5 minutes of exercise and changes in rectal temperature after exercise had ceased. Both the relative humidity and the clothing ensemble affected recovery; combat clothing at 40% relative humidity showed the slowest increase in T_R and NBC clothing at 80% relative humidity the fastest. T_R of volunteers wearing the Tyvek overgarment increased at a slower rate than those wearing the NBC ensemble, the differences at 80% relative humidity being significant after 10 and 15 minutes recovery time ($p > 0.95$ at 10 minutes and $p > 0.9$ at 15 minutes).

Heart rates of volunteers decreased by the same amount after 5 minutes' rest in each environment regardless of the clothing worn (see Figure 2). However, a significant difference ($p > 0.99$) in heart rate decrement after 5 minutes' rest was found between the two environmental conditions. Mean heart rates fell by 42 beats per minute at 40% relative humidity and 34 beats per minute at 80% relative humidity.

Summarising, the protective clothing ensembles produced the following results when compared with combat clothing:

1. Body temperature rose one-and-a-half times as fast.

2. Heart rate increased by 80%.

3. Endurance times were reduced by 60% based on the same body temperature after exercise. If allowence is made for the continued temperature rise after ceasing exercise endurance times will be reduced even further.

4. Weight loss was 40% higher.

5. Sweat evaporation was halved.

4. DISCUSSION

The condition of 30°C and 80% relative humidity employed in the current work is similar to that likely to be met in tropical or sub-tropical jungle which is found in coastal regions of northern Australia and in the countries of South-East Asia and the Pacific. Typical conditions are warm and humid with minimal air movement and little or no solar radiation. The moderate to heavy work rate of the volunteers is also not unrealistic in military terms. The results supported the previous conclusion [3] that

troops caught in a contaminated environment in warm and humid regions could, at best, only adopt a defensive posture. Normal military activity would be severely restricted. High water losses would also compound the problems faced by commanders in such conditions. Losses of 2 litres an hour occurred when protective clothing was worn. Even in combat clothing volunteers lost 2 litres an hour when the relative humidity was 80%.

Another feature of the results was the continued increase in rectal temperature after men had ceased exercise. The rectal temperature of volunteers dressed in the NBC clothing was still rising 15 minutes after they had stopped walking and had increased by 0.6°C when the relative humidity was 80%. When the combat clothing was worn the increase was about 0.1°C and rectal temperatures began to drop after about 8 minutes' rest. The consequence of these observations is that men working in NBC clothing will need to cease work at a much lower body temperature, possibly 38.5°C, if they are not to become heat casualties. When dressed in combat clothing a body temperature of 39°C could probably be tolerated before a rest was necessary. It can be deduced from Figure 1 that after a recovery period at least as long as the exercise duration the subjects wearing NBC clothing will not have returned to their original state.

The lightweight Tyvek overgarment and the NBC suit caused almost identical physiological responses in volunteers wearing them. The only significant difference occurred when the volunteers rested after exercising. Here, the Tyvek suit allowed a faster recovery as evidenced by the smaller increase in rectal temperature (see Figure 1). This effect is probably due to: (i) the thinness (0.15 mm) of the Tyvek fabric, (ii) its single-layer construction and (iii) the snug fit of the Tyvek suit. The last two factors mean that the amount of air and thickness of air layers held around the body are reduced in comparison to the loose-fitting, two-layer NBC suit.

The concept of a lightweight impermeable suit for use in warm and humid conditions appears to be worth further study. This preliminary investigation has indicated that a suit like the Tyvek one examined compares favourably with the UK No. 1 Mk 3 NBC suit in terms of the heat burden imposed on the wearer. The lightweight suit has the added advantages of low weight (156 g compared to 1450 g), low bulk (900 cm^3 compared to 3000 cm^3 for the vacuum-packed UK suit) and low cost (approximately 5 dollars compared to 50 to 100 dollars). It should be noted that Tyvek fabric is not impermeable to air but its permeability is so low that it cannot be measured using standard textile permeability tests. Its chemical protective capability is also limited. Further studies are required to determine whether a lightweight impermeable suit with acceptable protective properties can be found which still possesses the advantages of the Tyvek suit examined here.

5. ACKNOWLEDGEMENTS

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TABLE 1

PHYSICAL CHARACTERISTICS OF PARTICIPANTS

Subject No.	Age (Yrs)	Height (cm)	Weight (kg)	Body Surface Area* (m^2)
1	39	179.5	70.0	1.88
2	26	175.0	68.2	1.82
3	31	173.0	73.4	1.87
4	30	182.0	77.0	1.98
5	28	173.5	68.9	1.82
6	24	178.5	71.4	1.89
7	[illegible]6	183.0	73.4	1.95
8	39	179.5	71.0	1.89
9	29	176.5	66.0	1.81
10	27	178.0	81.8	2.00
11	22	185.0	74.0	1.97
12	35	183.0	69.4	1.90

* Calculated from the equation (4):

$$\text{Area} = \text{Weight}^{0.425} \times \text{Height}^{0.725} \times 0.007184$$

TABLE 2

TREADMILL RESULTS AT 30°C AND 40% RELATIVE HUMIDITY FOR MEN WEARING COMBAT CLOTHING

Subject	Duration (min)	Load (kg)	Rectal Temp (°C)		Heart Rate (bpm)		Weight Loss* (kg)	Sweat Evap'd† (%)
			Initial	Final	Initial	Final		
1	60	20.5	36.9	38.35	54	138	0.55	100
2	60	22.1	37.7	38.8	72	156	1.05	62
3	60	20.7	37.45	38.95	45	156	1.60	41
4	60	20.7	37.6	38.6	60	150	1.15	61
5	60	21.7	37.2	38.2	78	126	0.65	85
6	60	22.0	37.2	38.55	60	146	1.15	65
7	60	22.7	37.5	38.7	72	158	0.95	74
8	60	19.8	37.4	38.6	60	108	0.90	61
11	60	21.6	37.4	37.95	84	126	0.90	78
12	60	20.3	37.1	38.6	78	180	1.45	52
Mean	60	21.2	37.35	38.53	66	144	1.04	68
S.D.	0	0.9	0.24	0.29	12	21	0.32	17

* Nude weight

† $\frac{\text{(Nude weight loss) - (weight lost from fully-equipped subject)}}{\text{(Nude weight loss)}} \times 100$

TABLE 3

TREADMILL RESULTS AT 30°C AND 80% RELATIVE HUMIDITY
FOR MEN WEARING COMBAT CLOTHING

Subject	Duration (min)	Load (kg)	Rectal Temp (°C)		Heart Rate (bpm)		Weight Loss (kg)	Sweat Evap'd (%)
			Initial	Final	Initial	Final		
1	50	20.5	36.95	38.8	60	156	1.05	33
2	50	21.10	37.5	39.2	84	174	1.4	36
3	50	21.5	37.55	39.05	60	168	1.65	24
4	45	21.0	38.0	39.3	78	168	1.20	33
4	45	20.8	37.8	39.2	66	176	1.50	30
5	55	21.0	37.4	39.1	78	156	1.35	33
6	43	20.1	37.8	39.2	78	168	1.30	35
7	55	21.4	37.4	39.2	90	174	1.50	40
8	53	20.7	37.35	39.2	78	156	1.75	26
9	60	19.9	37.4	39.2	80	174	1.4	36
10	60	20.2	37.45	39.1	114	180	2.05	34
11	60	20.5	37.4	39.2	84	174	1.60	34
12	48	20.6	37.4	38.95	84	186	2.10	21
Mean	52	20.7	37.49	39.13	80	170	1.53	32
S.D.	6	0.5	0.26	0.13	14	9	0.31	5

TABLE 4

TREADMILL RESULTS AT 30°C AND 40% RELATIVE HUMIDITY
FOR MEN WEARING NBC CLOTHING

Subject	Duration (min)	Load (kg)	Rectal Temp (°C)		Heart Rate (bpm)		Weight Loss (kg)	Sweat Evap'd (%)
			Initial	Final	Initial	Final		
1	60	25.0	36.85	38.8	60	180	1.0	35
2	35	25.1	37.6	39.2	84	176	0.8	25
3	35	25.3	37.8	39.0	60	158	1.45	21
4	40	25.2	37.55	38.6	84	186	1.10	32
5	60	25.0	36.9	39.0	66	158	1.30	31
6	38	25.7	37.5	39.2	72	180	0.85	47
7	40	25.6	37.25	38.5	78	180	1.0	35
8	45	25.3	37.1	38.6	78	162	1.25	28
11	60	24.9	37.2	39.2	78	182	1.55	32
Mean	46	25.2	37.31	38.90	73	174	1.14	32
S.D.	11	0.3	0.33	0.28	9	11	0.26	7

TABLE 5

TREADMILL RESULTS AT 30°C AND 80% RELATIVE HUMIDITY
FOR MEN WEARING NBC CLOTHING

Subject	Duration (min)	Load (kg)	Rectal Temp (°C)		Heart Rate (bpm)		Weight Loss (kg)	Sweat Evap'd (%)
			Initial	Final	Initial	Final		
1	35	23.8	37.55	39.0	78	174	0.95	16
2	25	23.0	37.75	38.95	90	174	0.95	16
4	30	24.3	37.55	38.6	84	186	1.3	15
6	30	23.3	37.85	39.05	80	170	1.15	17
7	30	21.8	37.45	38.45	78	180	1.0	15
8	35	24.2	37.5	38.95	66	160	1.45	14
9	25	23.3	37.55	38.5	78	168	1.05	33
10	30	23.5	37.4	38.65	90	180	1.5	13
11	30	23.9	37.6	39.2	84	180	1.55	19
12	19	22.7	37.6	38.2	100	180	0.9	6
Mean	29	23.7	37.58	38.76	83	175	1.18	16
S.D.	5	0.6	0.13	0.32	9	8	0.25	7

TABLE 6

TREADMILL RESULTS AT 30°C AND 40% RELATIVE HUMIDITY FOR MEN WEARING TYVEK CLOTHING

Subject	Duration (min)	Load (kg)	Rectal Temp (°C)		Heart Rate (bpm)		Weight Loss (kg)	Sweat Evap'd (%)
			Initial	Final	Initial	Final		
1	50	23.9	37.0	38.85	78	180	0.8	44
2	40	24.1	37.55	39.2	96	178	0.85	29
3	42	24.0	37.6	38.6	48	156	1.35	26
4	40	23.8	37.6	38.8	90	186	0.95	37
5	60	23.5	37.1	38.9	60	168	0.95	42
6	35	24.0	37.65	38.95	84	186	0.8	38
7	40	24.3	37.45	39.05	72	180	0.95	37
8	45	23.8	37.25	38.9	68	168	1.35	22
Mean	44	23.9	37.40	38.91	75	175	1.00	34
S.D.	8	0.2	0.25	0.18	16	10	0.23	8

TABLE 7

TREADMILL RESULTS AT 30°C AND 80% RELATIVE HUMIDITY
FOR MEN WEARING TYVEK CLOTHING

Subject	Duration (min)	Load (kg)	Rectal Temp (°C)		Heart Rate (bpm)		Weight Loss (kg)	Sweat Evap'd (%)
			Initial	Final	Initial	Final		
2	28	23.1	37.6	39.2	84	174	0.85	12
3	35	23.5	37.8	38.8	60	170	1.3	12
4	30	22.9	37.8	38.55	78	180	1.4	14
6	38	21.7	37.45	39.15	66	174	1.3	12
7	35	23.4	37.25	38.8	72	175	1.05	14
8	35	22.9	37.65	39.05	66	156	1.4	14
9	30	21.7	37.6	39.1	90	180	1.0	15
10	30	22.4	37.85	38.65	90	180	1.55	16
10	30	21.5	37.95	38.65	84	180	1.5	20
11	40	22.1	37.2	39.05	78	184	1.4	18
Mean	33	22.5	37.62	38.90	77	175	1.28	15
S.D.	4	0.7	0.25	0.24	11	8	0.23	3

TABLE 8

TREADMILL RESULTS AT 30°C AND 40% RELATIVE HUMIDITY FOR MEN WEARING PVC CLOTHING

Subject	Duration (min)	Load (kg)	Rectal Temp (°C)		Heart Rate (bpm)		Weight Loss (kg)	Sweat Evap'd (%)
			Initial	Final	Initial	Final		
1	43	24.9	36.8	38.35	66	180	0.7	21
2	35	24.5	37.6	39.2	78	180	0.85	12
3	25	25.0	38.05	38.8	66	176	0.85	18
4	30	24.9	37.95	38.8	78	180	1.05	19
5	40	24.2	37.15	39.2	72	162	1.2	17
6	30	25.1	37.35	38.6	78	186	0.85	29
7	30	25.0	37.4	38.45	84	182	0.6	25
Mean	33	24.8	37.47	38.77	76	178	0.87	20
S.D.	6	0.3	0.44	0.34	6	8	0.20	6

T A B L E 9

TREADMILL EXERCISE.[a] CHANGES IN RECTAL TEMPERATURE (ΔT_R) AND HEART RATE (ΔHR) IN THE 5 TO 30 MINUTE EXERCISE PERIOD

Clothing Ensemble	40% Relative Humidity		80% Relative Humidity	
	ΔT_R (°C)	ΔHR (beats/min)	ΔT_R (°C)	ΔHR (beats/min)
Combat	0.56 ± 0.11[b]	20 ± 6	0.79 ± 0.15	25 ± 8
NBC	0.84 ± 0.22	35 ± 7	1.20 ± 0.20	41 ± 10
Tyvek	0.84 ± 0.18	36 ± 3	1.01 ± 0.31	48 ± 7
PVC	1.03 ± 0.23	40 ± 12	c	

a Temperature 30°C.

b Mean and standard deviation.

c PVC ensemble not tested at 80% relative humidity.

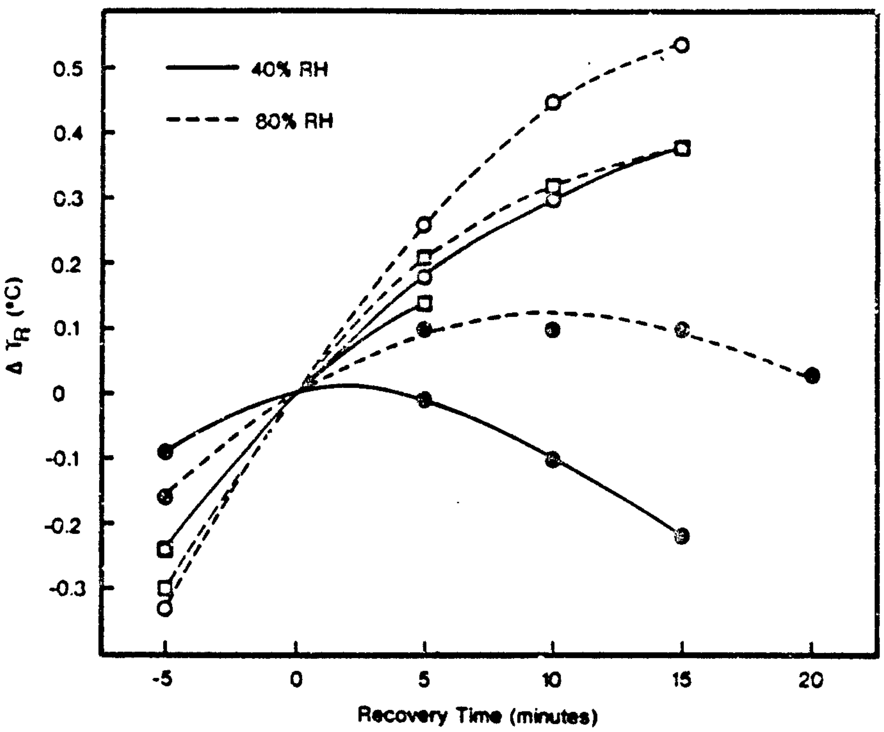

FIGURE 1 Changes in the Rectal Temperature of Volunteers Resting after Exercise (● - combat clothing, O - NBC clothing, □ - Tyvek clothing).

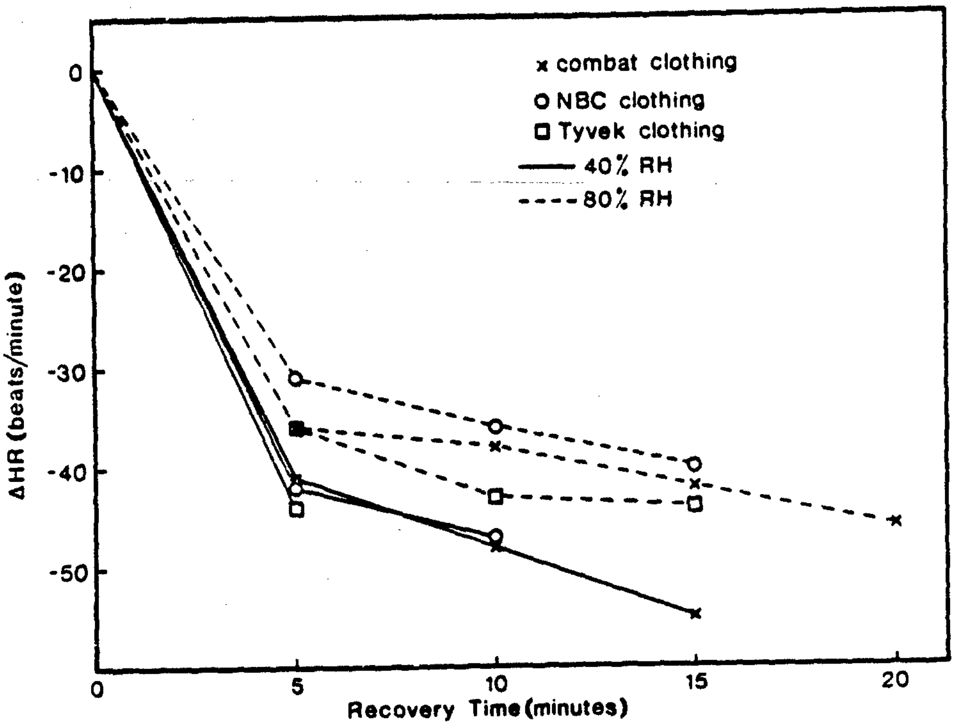

FIGURE 2 Changes in the Heart Rate of Volunteers Resting after Exercise.